A New Routine to Simulate Plasma Density Measurements from Satellites: Application to the SPORT Project

Ana Paula Lopes Schuch, João Pedro de Jesus Pereira Borher Jardim, Marco Antonio Ridenti, Willer Gomes dos Santos
Aeronautics Institute of Technology
São José dos Campos, São Paulo, Brazil
e-mail: aridenti@ita.br

Abstract—In this work, we simulated plasma density measurements along prescribed satellite circular orbits, varying the inclination in relation to the geographic equator. The IRI (International Reference Ionosphere) code was used to simulate the ionosphere and the orbits were simulated using a MATLAB® code. We developed a routine to interpolate the densities along the trajectory and plot the density curves measured by the satellite over time. We show how this curve is influenced by the inclination of the orbits and also by the time when the satellite crosses the magnetic equator. It was concluded that, over the Brazilian sector, curves that pass through conjugated points along the magnetic equator during the day tend to present the two peaks corresponding to the Appleton anomaly in a pronounced way. Due to the typical declination of the magnetic field in the Brazilian sector, the inclination of the CubeSat orbit of the SPORT (Scintillation Prediction Observation Research Task) project, of 51.6°, meets this condition for descending orbits. Analyzing complete trajectories at inclination angles of 51.6°, it was verified that the magnetic equator crossing time significantly influences the observed peaks related to the anomaly. The simulations also showed significant differences between different orbits that pass through the equator at the same local time but in different geographic regions, showing morphological differences in the Earth's magnetic field. The methodology developed here will be used in the interpretation of the experimental results obtained from SPORT, allowing direct comparison between simulation and measurement.

I. Introduction

The SPORT (Scintillation Prediction Observations Research Task) is a nano-satellite, from the CubeSats group, whose scientific objective is to study the conditions of the ionosphere that favor the formation of plasma bubbles. These bubbles affect the propagation of electromagnetic waves and signals, a phenomenon known as scintillation, affecting air navigation and communication services. It is also part of the scientific goals to better understand how bubbles relate to the observed scintillation effects of the Earth.

The development of both the space sector and science in general has made it possible to produce smaller and cheaper measuring devices. CubeSats emerge in this new scenario: they are small satellites and, in general, low cost, compared to traditional satellites [1]. Therefore, they have become an alternative for universities and research institutions to build their equipment for space exploration.

In this context, the simulation of how satellite instruments respond to variations in the ionosphere is essential to avoid the choice of inappropriate trajectories and, consequently, loss of money and material. There is another important motivation: it is convenient to have at hand a routine capable of interpolating the electronic density obtained from the simulations along the satellite's orbit, so that the measurements can be directly compared with the simulation results.

In this work, the IRI (International Reference Ionosphere) [2] was used to simulate the ionosphere. This code is based on a semi-empirical mathematical model, built from experimental data. The code makes it possible to obtain the temporal profile of the ionosphere in any given geographic region.

Therefore, the objective of this work is to simulate the electronic density seen by a satellite using the IRI, first under the Brazilian sector and, finally, over the full period of the orbital motion. In addition, it is intended to verify how the electronic density curves vary as a function of the parameters related to flight dynamics, such as orbit inclination and magnetic equator crossing time, as well as verifying how the curves vary as a function of the behavior of the ionosphere, which depends on the time of day, season and solar cycle.

II. Methods

The IRI code provides the electronic density and other properties of the ionosphere for a given geographic coordinate and altitude. It also has the option of determining these properties along some iteration variable (for example, altitude, longitude, and universal time). To obtain the properties of the ionosphere at points distributed in a three-dimensional grid, as a function of universal time, it was necessary to carry out some code modifications, since the original code only iterates over one variable at a time. After the modification, we were able to iterate over all the coordinates (altitude, longitude and latitude) and time, and build a scalar field in a three-dimensional grid.

Once we have the electron density as a scalar field in a grid of space and time, we shall next determine the electronic density as seen by a satellite along its trajectory. Firstly, we transformed the grid points to polar coordinates (obtaining two variables, latitude and longitude - since the radius was considered constant) and, after that, we performed an interpolation, given that the position of the satellite, described by two spatial coordinates and a temporal coordinate, does not necessarily coincide with the plasma density grid. For this, the interpndo MATLAB® function was used to perform a linear interpolation. In addition, we had also to represent the magnetic equator curve in our analysis, which was obtained with data from the IGRF13 program [3] and further processed in our code. We used the MATLAB® contour function to determine the coordinates in which the vertical component of the magnetic field is null. Finally, the intersection coordinates (latitude and longitude) between the satellite trajectories and the magnetic equator curve were obtained with the code made by Douglas M. Schwarz [4], and the time of crossing was also computed.

III. Results

In our analysis, we show how the plasma densisty measured by satellites as a function of time are influenced by the inclination of the orbits and also by the time when the satellite crosses the magnetic equator. We shall discuss these results in detail in our presentation.

Here we shall present and discuss one of the results. By simulating some trajectories at inclination angles of 51.6°, we observed some remarkable differences between different orbits that pass through the equator at the same local time but in different geographic regions (Fig. 1). These differences are due to morphological differences in the geomagnetic field. The orange trajectory, starting (highest latitude) at longitude 244° passes through the South Atlantic region, where the Magnetic Anomaly and a local increase in electronic density occur. The IRI code captures this effect. Another interesting effect is the difference in transit time at the second peak (night peak). In the case of the blue curve, representing the measurement of the satellite in orbit starting at 357°, this second peak occurs earlier, which is due to the fact that the crossing with the magnetic equator occurs further south in this case.

IV. Conclusion

In this work, we developed a routine to determine the expected plasma density as a function of time, using the IRI as the physics input that describes the ionosphere. We shall explore the conclusions in detail in our presentation and now we summarize it in general terms.

By analyzing circular orbits with distinct inclination angles in the Brazilian sector, we concluded that those orbits that are parallel to the magnetic equator do not present so many variations in electronic density along their path. Due to the typical declination of the magnetic field in

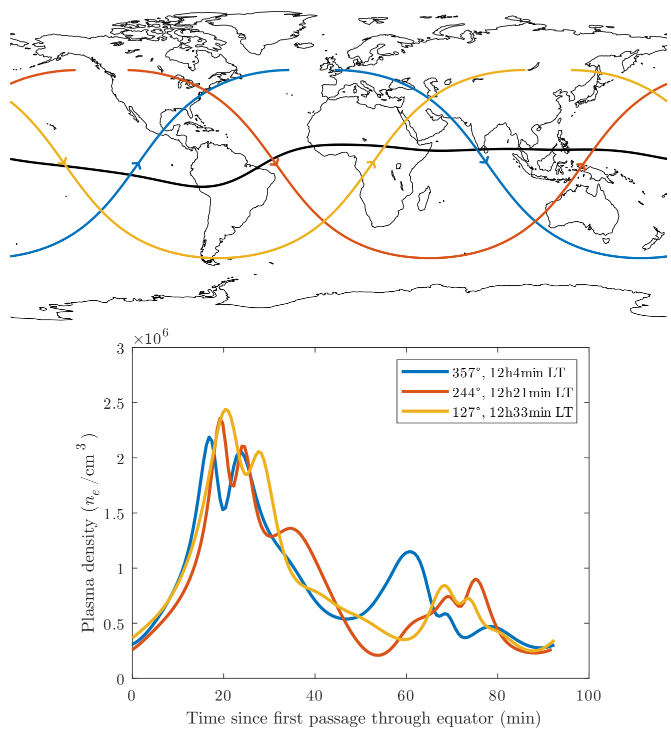

Fig. 1. On the left, the trajectories represented on the map. On the right, the electronic density measured on each of the trajectories. In the legend, the longitude of the beginning of the trajectory and the local time of the first intersection with the magnetic equator are indicated.

the Brazilian sector, the inclination of the CubeSat orbit of the SPORT project, of 51.6°, must cross conjugate points in the case of descending orbits, so that the Appleton anomaly should be detected.

ACKNOWLEDGEMENT

We acknowledge the Brazilian funding agency CNPq (National Council for Scientific and Technological Development) for the undergraduate research scholarship granted to authors João P. Borher and Ana P. Schuch (Process 112013/2020-1). We also acknowledge the Brazilian agency FAPESP (São Paulo Research Foundation) for funding the project SPORT under process 16/24970-7.

References

[1] A. Poghosyan, and A. Golkar, "CubeSat evolution: Analyzing CubeSat capabilities for conducting science missions", Progress in Aerospace Sciences, vol. 88, pp. 59–83, January 2017.

[2] D. Bilitza, "IRI the International Standard for the Ionosphere", Advances in Radio Science, vol. 16, pp 1–11, September 2018.

[3] P. Alken, E. Thébault, C. D. Beggan et al."International Geomagnetic Reference Field: the thirteenth generation". Earth Planets Space, vol 73, pp 49, February 2021.

[4] D. M, Schwarz, 2017. Fast and Robust Curve Intersections. https://www.mathworks.com/matlabcentral/fileexchange/11837-fast-and-robust-curve-intersections. Accessed in August 2020.